Finding Renewable Energy Solutions Through GIS

Delaney Hanson

Point Loma Nazarene University

Honors Research Project

Committee: Lori Carter, Ph.D. (Mentor); Robert Gailey, Ph.D.; Mike Leih, Ph.D.

June 18, 2021

Table of Contents

Abstract

This project explores Esri's ArcGIS tool and uses its functionality to map out ideal renewable energy locations in specific areas in the United States. Depending on the type of energy source, different factors are considered to draw conclusions about the best places to implement renewable energy power plants. Research into GIS data and renewable energy factors helped guide the search for the datasets that this project required. This paper describes not only the results of ideal locations that were discovered, but also the process of learning and applying the various tools and techniques for the research. The tutorials provided for ArcGIS, demonstrated how the application displays datasets and uses processing tools to manipulate data on a map. The layers that were obtained provided insight to analyze the conditions which would create an ideal site for a solar or wind power plant.

I. Background

A. Need for Renewable Energy

According to the Energy Information Administration, in 2019 only eleven percent of the United States' energy consumption came from renewable energy sources ("U.S. Energy Facts Explained," 2020). All other energy came from either nuclear or fossil fuel energy sources. Renewable energy sources are unique because they are a source of "clean energy" which means they come from natural sources that are continually restored and theoretically inexhaustible. Fossil fuels, such as oil and coal, are diminished each time we use them. In a *National Geographic* article about non-renewable energy sources, Morse explained that we can and will run out of these resources eventually (2013), so renewable energy sources hypothetically provide unlimited energy that cannot be depleted by harnessing the geographic and natural resources of a certain terrain.

One way that we can look at the geography and conditions of a certain area is by using a Geographical Information System (GIS). It allows us to visualize multiple layers of data on a map and perform analyses easily with its included functions. Some examples of daily use of GIS systems include phone communication networks, road network design and transportation infrastructure, medical emergency vehicles routes, and planning new stores and restaurants. Esri is a company that is dedicated to advancing technology in this field and building a community of users to educate through their tools (https://www.esri.com/en-us/home). ArcGIS is the system that Esri developed, and it includes the ability to create layers of datasets for analysis as well as the StoryMap function which helps users tell a visual narrative of the data they found and the conclusions drawn from it. One common real-world example of daily use of GIS can be seen through navigation apps on smartphones. Layers of GIS data are applied to a map to inform a user of roads, traffic signals, gas stations, and many other aspects that are included to help navigate. The process of building maps with GIS will be expanded on later.

B. Background Required for Project

When deciding where to implement a renewable energy project, one must consider the environmental advantages, weather conditions, and other factors that make a piece of land suitable. For the project, a decision was made to focus on solar and wind energy because those two are the most popular renewable energy sources in the United States. Some of the factors that improve or decrease solar production are cloud cover, temperature (heat build up), elevation, humidity, and sun intensity (Solar Energy Technologies Office, n.d.). Rising temperatures can cause heat build up and lead to lessened outputs of solar energy. Shade depends on cloud coverage, so areas that are cloudy more frequently will decrease solar production. Reduced solar production occurs because the clouds interfere with the sun's rays that are trying to reach the panels. Humidity can also disrupt the solar panels' performance, and it can cause permanent damage at certain levels. Additionally, the higher up in elevation the panels are located, the less distance solar rays have to travel; as elevation increases, so does solar radiation.

Wind energy relies on a completely different set of factors, as does each renewable energy source. Performance can be predicted by looking at wind speed, area between turbines, and air density. Lower, consistent wind speeds are more important than inconsistent high-speed winds. The ideal wind speed is between 13 and 50 km/h (NYSERDA, n.d.). Blade radius must also be considered when planning the turbines because they have to be a certain distance apart to function properly. Higher density air can improve turbine performance because it applies “more pressure on the rotors” and yields a larger output in power.

II. Methods

A. Data Search

The search for datasets that would be applied to the map was a completely unfamiliar and new process. The research began with Googling “renewable energy datasets” which generated a large amount of general data on renewable energy that was not applicable to an ArcGIS map. More research revealed that the datasets must have fields for x and y coordinates to be applied to a map, among other attributes, and there were certain file types that were better suited for GIS. The search of renewable energy data also became refined to more specific inquiries such as GIS data that correlated to certain factors of wind and solar energy that were mentioned previously. Websites were found that provided GIS data for weather or energy factors and also learned how to apply the online Esri datasets to the map in ArcGIS. The tutorials through Esri with the ArcGIS software and the research into GIS formats showed that the current searches were looking into the wrong type of data; the research for data was not specific enough, and it was not specific to the file type that would be compatible with an ArcGIS map. There are numerous types of formats that can be applied to an ArcGIS map. Some of those include feature layers, rasters, Keyhole Markup Language (KML) files, shapefiles, etc. After an understanding of the required files was established, the search for the right data was improved.

B. Learning to Build Maps

Before beginning to work in ArcGIS, it was necessary to become familiar with the basics of the program. Various components of the software that are available to its members were researched: tutorials, analysis tools, and story maps. This research was helpful for learning about ArcGIS functions and features, and it demonstrated the introductory skills to begin creating the map for the project.

ArcGIS provides tutorials for its users through their Learn ArcGIS Lesson Gallery (https://learn.arcgis.com/en/gallery/). The gallery consists of various lessons to follow along with or videos and articles to view. In addition, users can filter the tutorials based on categories such as capability, product, topic, type, region, and role. As the learning process began for ArcGIS, this resource helped familiarize the tools included in the software and how to use them when given data.

After completing tutorials, the map for the project was ready to be started from scratch. When importing data to the map from online sources, issues arose when trying to display the features of the layer. Much of the troubleshooting involved searching online forums, and Esri has a community forum for its users to interact and help one another. The solution to the problem was found among the Esri community in a post about KML file issues. In ArcGIS' analysis toolbox is a geoprocessing tool that converts KML files to a layer file. This tool was utilized on an imported solar insolation dataset to correct the image and display the correct symbology. Additionally, the buffer tool was applied to an electrical transmission lines layer. Each power plant must be either adjacent to or a few hundred yards away from an existing transmission line. This tool allows the user to specify the distance away from each line the buffer would expand. As a result, the tool creates a new buffer layer that can be applied to the map after processing the parameters.

Another aspect of ArcGIS that was explored is manipulating the symbology of different map layers. The symbology refers to how certain features of a layer are displayed on the map. When importing some datasets to the ArcGIS environment, the symbology was either skewed or needed some adjustment. It was altered so the layers appeared correctly on the map, and the labels were fixed on the legends so that it matched the source of the dataset.

Lastly, a valuable aspect learned was that Esri provides a story maps feature. Story maps combine the maps that users create in ArcGIS and allow them to develop a narrative for their audience. It can be difficult for the layperson to interpret all the data presented on the map, so these story maps present a unique way to relay data to people unfamiliar with the project map created on ArcGIS.

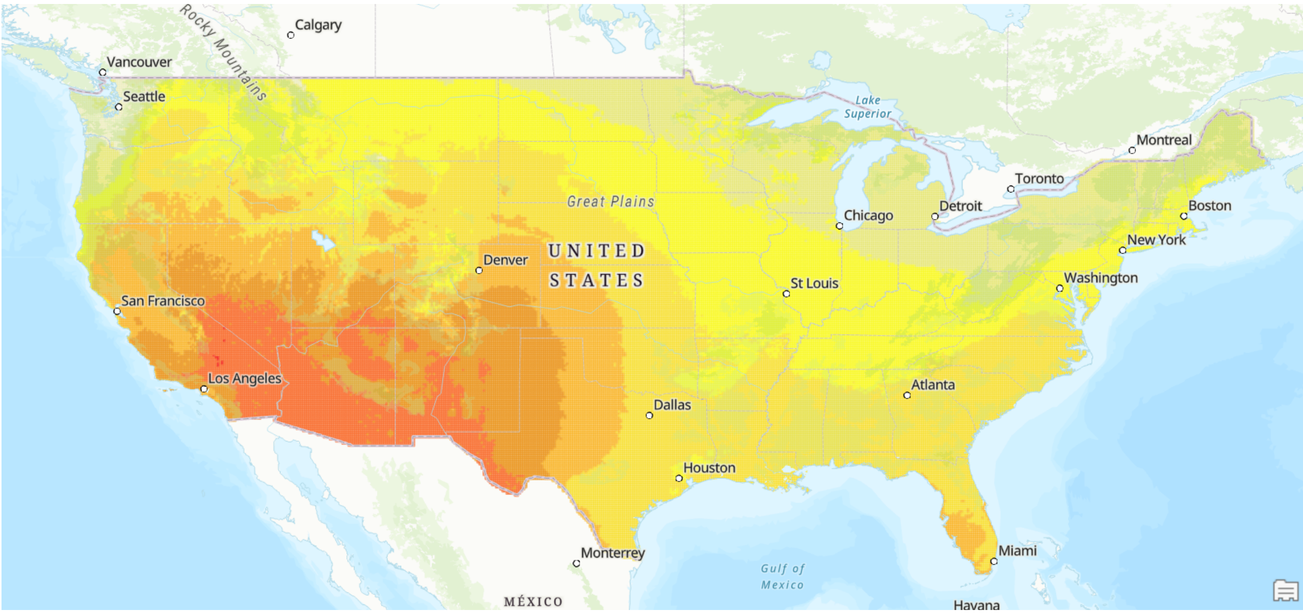
C. Determining the Target States

Upon some brief research into the factors, certain states were found to be better-suited for either solar or wind energy production. Initially, the contiguous United States was going to be the focus, but it was narrowed down to two states each for wind and solar to be able to make a more specific analysis. A program was created that looked at the size of the state and the number of solar or wind facilities already implemented. The output would help conclude which states had the most space to expand for a particular renewable energy source. Datasets were searched for that contained the number of power plants in each state in the U.S., and the Energy Information Administration (EIA) has created the U.S. Energy Atlas which contains data and maps pertaining to the country's energy framework and resources. A spreadsheet was downloaded of two datasets, one with the locations of each wind power plant and the other with the locations of each solar power plant in the United States ("Wind," 2020; "Solar," 2020). The second dataset obtained was the land area per state ("Size of States," n.d.). From there, the CSV file was filtered to keep the fields that were necessary for the program. Please see Appendix to reference this program's code.

The first program, *PlantByState.java*, read in both files that contained the locations for the states' power plants. A method was created, countFrequencies, that used the Collections framework in Java and the frequency method to count the number of occurrences of power plants per state. Once that was determined, those numbers were combined and they were organized with the land area for each state. The second program, *StateSunWindCalculator.java*, read from the file containing the state name, area, and number of solar or wind plants for each state and compared them. The area was divided by the number of plants to produce a number that would represent the land potential to expand renewable power plant sites. Please see Appendix to reference this program's code. The combination of the numbers produced from this program and some research into the wind and solar potential for each state narrowed down the focus to two states for solar power plants, Kansas and Texas, and two states for wind power plants, Montana and South Dakota.

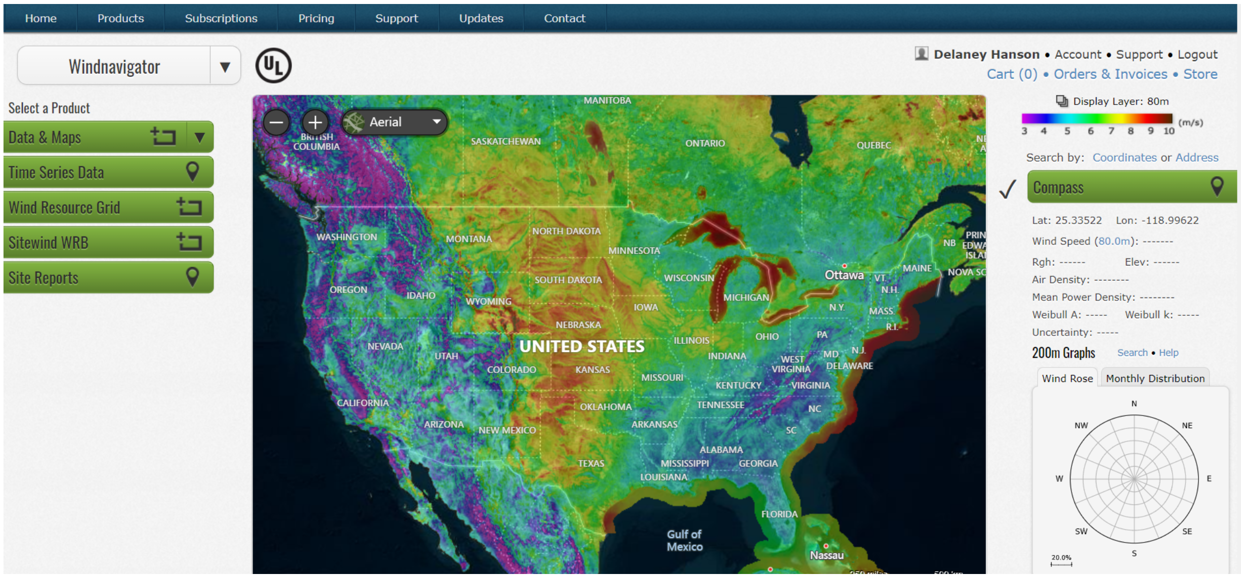
D. Creating the Map

One of the key components of maps created in ArcGIS is the ability to import datasets and display them as layers. The combination of layers helps the user visualize the data and draw conclusions from it. When this project started, it was known that the factors that were researched for solar and wind energy would be used as layers on the map. The initial searches for solar layers included factors such as cloud coverage, air density, and elevation. While looking for this GIS data, the process proved to be difficult to find these individual datasets. Eventually, more research helped find the terms solar irradiance and insolation which takes into account a variety of the factors that were being searched for. The RE Atlas (https://maps.nrel.gov/re-atlas/), developed by the National Renewable Energy Laboratory, gives public access to a GIS map layer that displays "...monthly average and annual average daily total solar resource averaged over surface cells of 0.1 degrees in both latitude and longitude, or about 10 km in size" (NREL, n.d.). This layer (see Figure 1) measures solar insolation which considers the contents in the atmosphere such as aerosols, moisture, remnant gases, and snow cover. These factors affect the amount of insolation received by the surface where the solar panels are positioned. The units provided by the legend of the map are kWh/m^2/day, and they represent the peak sunlight hours per day which measures the number of hours per day that a certain area would receive sunlight if the sun were shining at its greatest capacity (Honsberg & Bowden, n.d.). At least four peak sun hours is an acceptable amount for solar panels to perform effectively (Hyder, 2021).



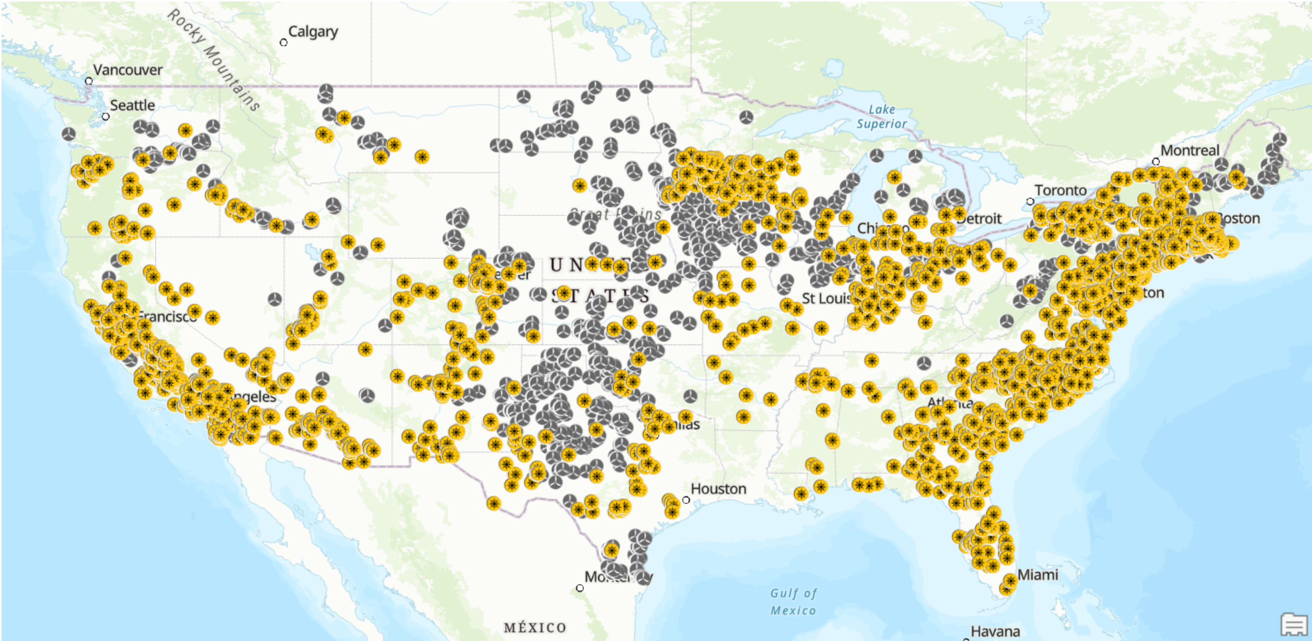
[Figure 1] Solar insolation map from NREL's Renewable Energy Atlas

GIS data regarding annual wind speeds in the United States was looked for to measure wind turbine performance. A few different maps were found that included a layer with this type of data, but when trying to download the file, the website said that the amount of data was either too large or required a payment of a considerable amount of money to have personal access to the data on the map. All resources were exhausted to find this information, and, ultimately, the wind speeds could not be displayed on the ArcGIS map with the rest of the layers. The map shown below is from AWS Trupower's WindNavigator application (see Figure 2), and it was referenced when making the final analysis. The software can be found at https://aws-dewi.ul.com/software/windographer/windnavigator/.



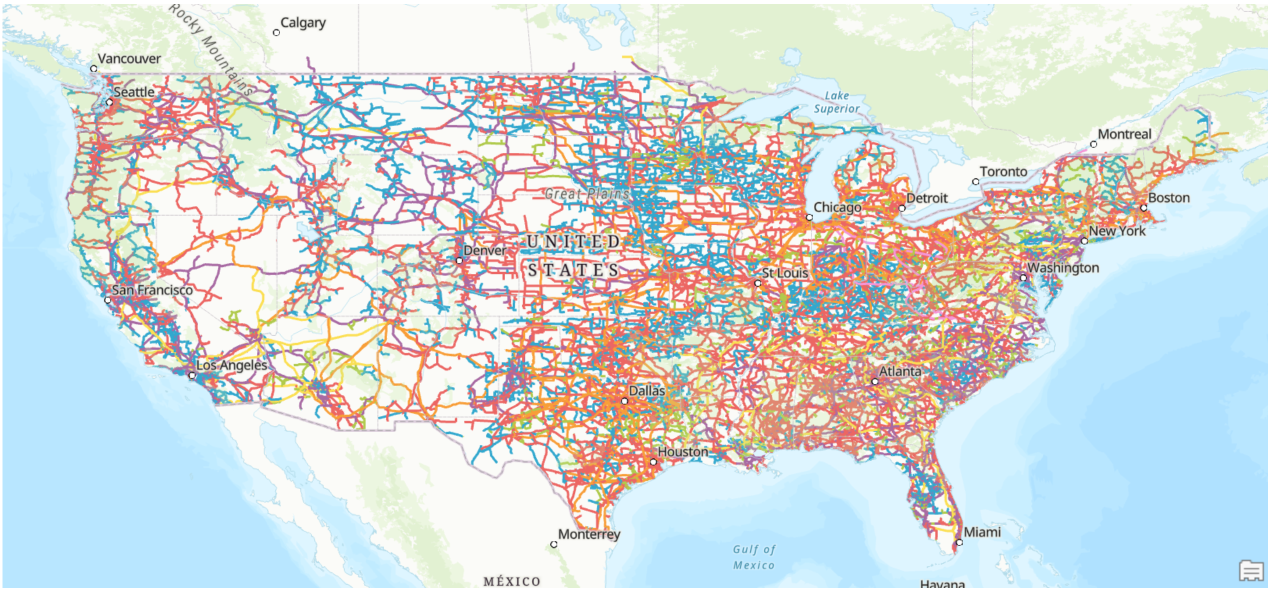
[Figure 2] Wind speed map from AWS Truepower's WindNavigator map

Another set of layers that were found through Esri's ArcGIS Living Atlas of the World was the locations and types of all power plants in the United States (see Figure 3). In the analysis, locations were not suggested for renewable energy plants in areas in which they were already established. With this layer, one is able to filter the type of power plant that appears on the map, so the positions of the wind and solar plants were focused on. Although not shown in the figure, this layer includes the locations of nonrenewable energy power plants as well as the renewable sites.



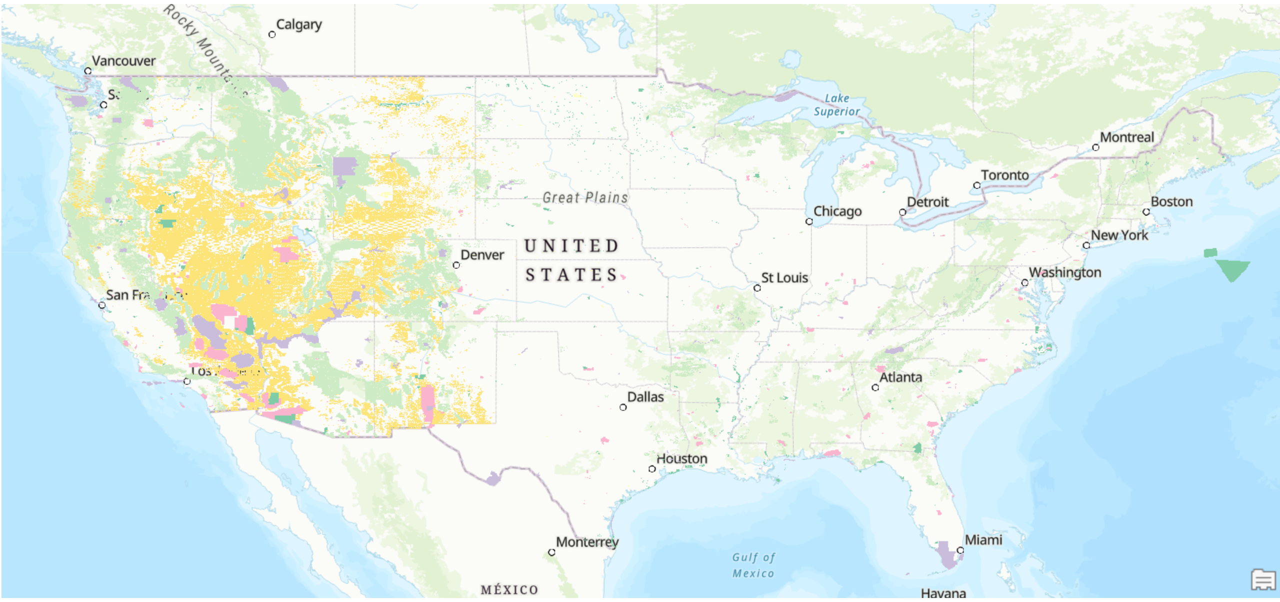
[Figure 3] Locations of solar and wind power plants in the U.S.

One of the other layers included provides the network of electrical transmission lines in the United States. When beginning the research, E. Koch (personal communication, Nov 9, 2020) at Sempra Energy was consulted to learn about the factors a company in the energy sector uses to determine sites for power plants. Koch suggested incorporating transmission lines into the project research. If a power plant is built too far from an existing line, the cost to build new infrastructure to reach the facility would be too expensive. Some search on the ArcGIS Living Atlas presented a layer that contains all the electrical transmission lines and the kilovolts allocated to each one (see Figure 4).



[Figure 4] The network of electrical transmission lines in the U.S.

Additionally, the locations of federal lands were incorporated onto the map (see Figure 5). There are various restrictions on the different types of lands and its ownership: Bureau of Land Management (BLM), Bureau of Reclamation, Department of Defense, Fish and Wildlife Service, Forest Service, and National Park Service. The land that the BLM manages can be sold but this is not a common occurrence due to the Federal Land Policy and Management Act of 1976 (FLPMA) (Vann, 2012). Most of this land is located in the western-most states. It would not be impossible to build renewable energy power plants on this land, but it would be more problematic than looking elsewhere.

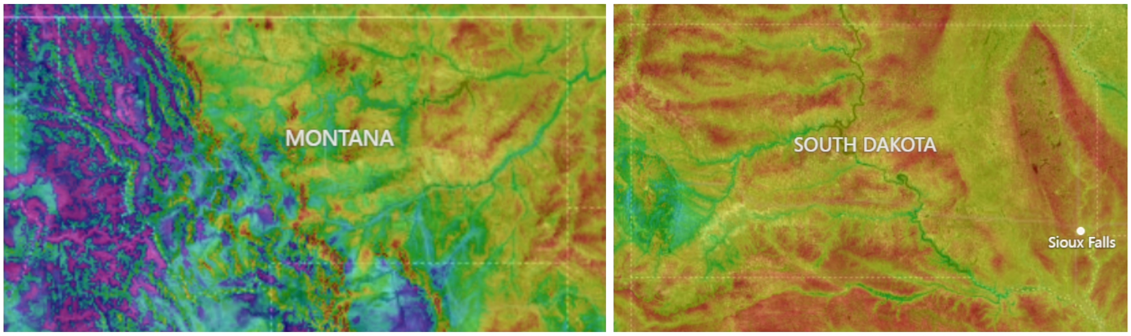


[Figure 5] Areas of federal land in the country, organized by ownership

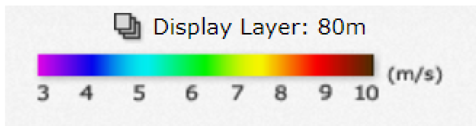
III. Results

A. Analysis

When preparing to make the analysis of the data, the correct layers were combined on the map that corresponded with either solar or wind energy -- there was some overlap of layers. To analyze the wind potential in Montana and South Dakota, these datasets were included: (wind) power plant locations, transmission lines and the buffer, federal land, state boundaries, and world topographic map. Since a GIS layer of the wind speeds was not able to be obtained, Figures 6-8 from AWS Truepower's WindNavigator application were referenced to examine where suitable wind speeds were in the states. Locations were chosen that had above 6 m/s wind speeds which includes the areas in green, yellow, orange, and red.

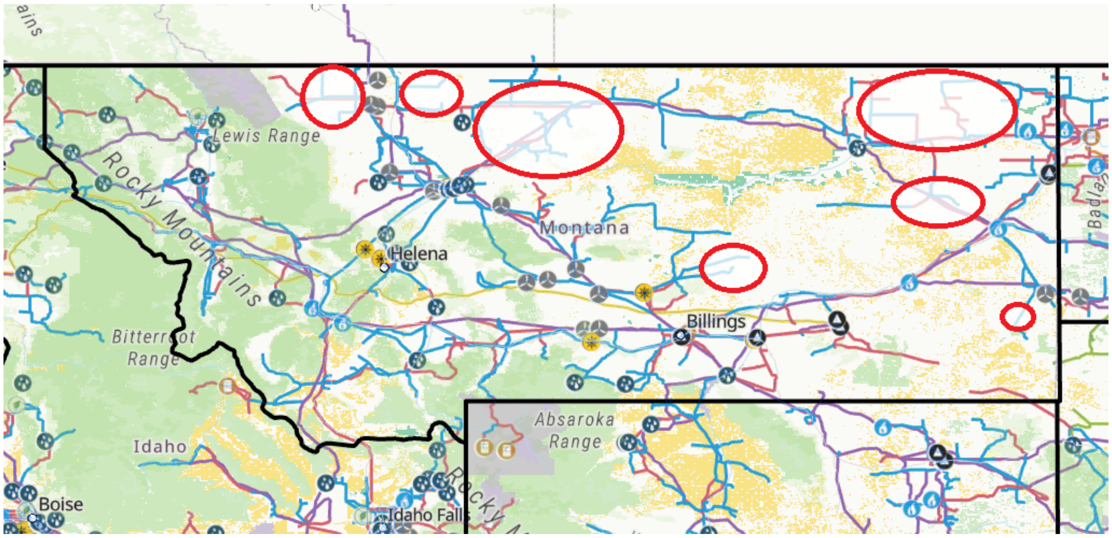


[Figures 6 & 7] The wind speeds in Montana and South Dakota

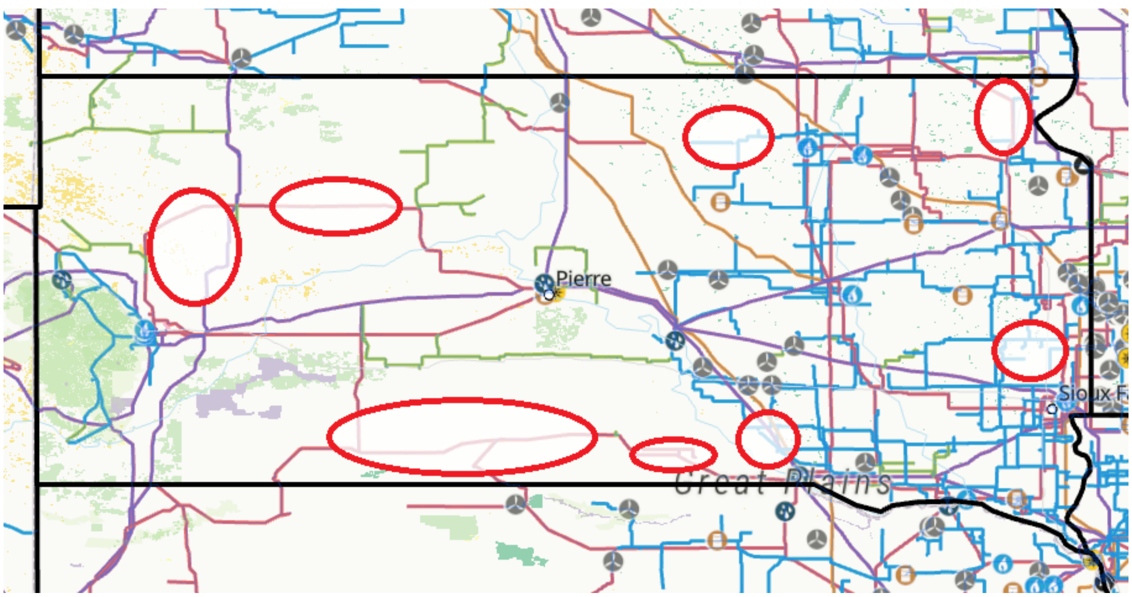


[Figure 8] The legend used on the WindNavigator map

Along with the wind speeds, the locations of other power plants were considered to make sure there was no overlap. Within the transmission lines layer, there was a featured line on the map that was declared "unavailable," so any use of that type of transmission line was removed from the final evaluation. Lastly, federal lands such as national parks and forests were avoided due to their restrictions and regulations. The final areas for potential growth for wind power in Montana and South Dakota can be seen in Figures 9 and 10.

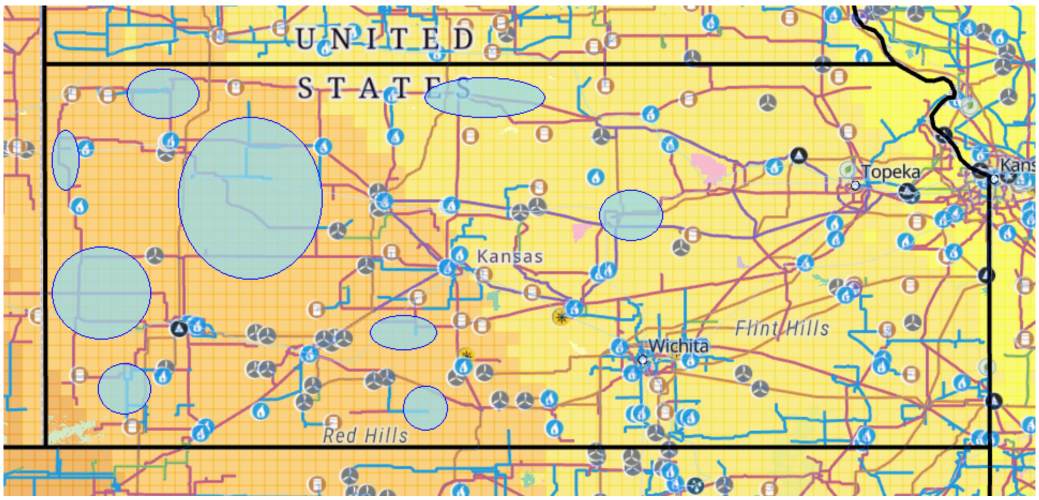


[Figure 9] Ideal locations for wind power in Montana

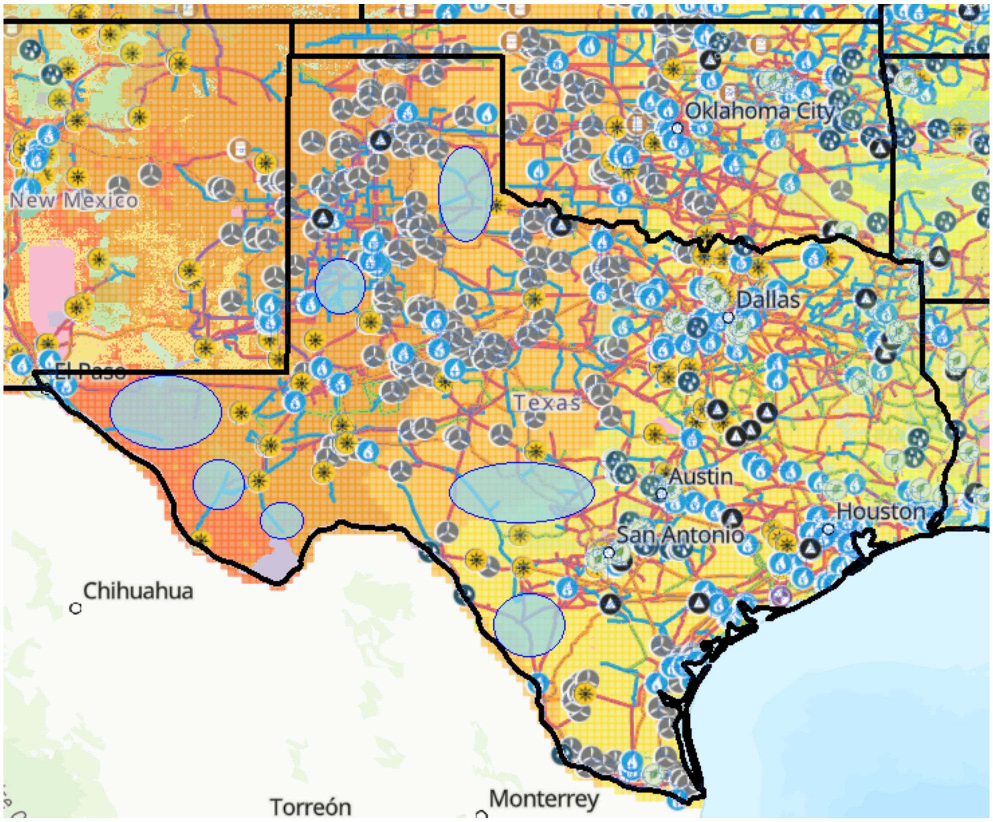


[Figure 10] Ideal locations for wind power in South Dakota

When applying the combination of layers to evaluate solar potential, these datasets were incorporated: solar insolation/irradiance, (solar) power plant locations, transmission lines and the buffer, federal land, state boundaries, and world topographic map. After research of solar insolation and the amount needed for effective solar panels, locations were chosen with at least 4.5 kWh/m²/day, or 4.5 hours of peak sunlight per day -- this measurement includes the areas in light orange to red on the map. In addition, the same requirements were applied to the transmission lines, power plants, and federal land as previously mentioned in the analysis of wind potential. The areas for ideal expansion are outlined in Figures 11 and 12 below.



[Figure 11] Ideal locations for solar power in Kansas



[Figure 12] Ideal locations for solar power in Texas

Final Considerations

This project introduced a tool that has potential to bring a person into a field of computer science and sustainability. The experience with ArcGIS helps one learn the basics of the program, and may spark a unique interest in GIS that can turn into a career path. There is a lot of opportunity to continue learning about the various features of ArcGIS, and this project only scratched the surface.

Appendix

PlantByState.java

```java
/*Written by Delaney Hanson*/

//import statements
import java.io.File;  // Import the File class
import java.io.FileNotFoundException;  // Import this class to handle errors
import java.util.*; // Import the Scanner class to read text files

import java.util.HashMap;
import java.util.Map;
import java.util.Map.Entry;

public class PlantByState
{
    //Method calculates number of power plants per state
    public static void countFrequencies(ArrayList<String> list)
    {
        //Hash set is created and elements of arraylist are inserted into it
        Set<String> st = new HashSet<String>(list);
        int count = 1;
        for (String s : st)
        {
            System.out.println(count + ". " + s + ": " + Collections.frequency(list, s));
            count++;
        }
    }

```

```java

    public static void main (String [] args)
    {
        //Create array lists to hold the names of the states being read in from the file
        ArrayList <String> stateSunAL = new ArrayList<String>();
        ArrayList <String> stateWindAL = new ArrayList<String>();

        //File 1
        try
        {
            File sunFile = new File("plantSUN.txt");
            Scanner myReader1 = new Scanner(sunFile);

            while (myReader1.hasNext())
            {
                String state = myReader1.next();
                stateSunAL.add(state);
            }
            myReader1.close();
        }
        catch (FileNotFoundException e)
        {
            System.out.println("An error occurred.");
            e.printStackTrace();
        }

```

```
        //File 2
        try
        {
            File windFile = new File("plantWND.txt");
            Scanner myReader2 = new Scanner(windFile);

            while (myReader2.hasNext())
            {
                String state = myReader2.next();
                stateWindAL.add(state);
            }
            myReader2.close();
        }
        catch (FileNotFoundException e)
        {
            System.out.println("An error occurred.");
            e.printStackTrace();
        }

        //Call countFrequencies method
        countFrequencies(stateSunAL);
        countFrequencies(stateWindAL);

    }
}
```

StateSunWindCalculator.java

```java
/*Written by Delaney Hanson*/

//import statements
import java.io.File;  // Import the File class
import java.io.FileNotFoundException;  // Import this class to handle errors
import java.util.*; // Import the Scanner class to read text files

import java.math.RoundingMode;
import java.text.DecimalFormat;

import java.util.HashMap;
import java.util.Map;
import java.util.Map.Entry;


public class StateSunWindCalculator
{
    public static void main (String [] args)
    {

        DecimalFormat df = new DecimalFormat("0.00");
        HashMap<Integer, String> map = new HashMap<Integer, String>();//Creating HashMap

        //ArrayList holds state names and array holds the percentages
        ArrayList <String> states = new ArrayList<String>();
        Integer [] percents = new Integer[50];


        //File 1
        try
        {
            File sunFile = new File("stateSqMileSun.txt"); //specify the file here
            Scanner myReader1 = new Scanner(sunFile);
            int counter = 0, counter2 = 0;

            //Read information in from the file
            while (myReader1.hasNext())
            {
                String state = myReader1.next();
                states.add(state);

                int sqMile = myReader1.nextInt();

                int plants = myReader1.nextInt();

                int percentLandAvailable;
                //If there are no solar or wind plants in a state,
                //avoid division by 0 and place at the top of the list by adding a large number
                if (plants == 0)
                {
                  percentLandAvailable = 100000 + counter2;
                  counter2++;
                }
                else
                {
                  percentLandAvailable = sqMile/plants;
```

```
                }

                //Place the percents and state names into the hash map
                percents[counter] = (Integer)percentLandAvailable;
                map.put((Integer)percentLandAvailable, state);

                counter++;
            }
            myReader1.close(); //close scanner

            //Sort the percentages in reverse order and print them out
            Arrays.sort(percents, Collections.reverseOrder());
            for(int i = 0; i < percents.length; i++)
            {
               System.out.println(i+1 + ". " + percents[i] + "   " + map.get(percents[i]));
            }

            //
        }
        //Catch error in case file is not found
        catch (FileNotFoundException e)
        {
            System.out.println("An error occurred.");
            e.printStackTrace();
        }
    }
}
```

Bibliography

Honsberg, C., & Bowden, S. (n.d.). *Average Solar Radiation*. https://www.pveducation.org/pvcdrom/properties-of-sunlight/average-solar-radiation

Hyder, Z. (2021, April 15). *What is a peak SUN hour? What are peak sun hour numbers for your state?* https://www.solarreviews.com/blog/peak-sun-hours-explained

Morse, E. (2013, February 14). *Non-renewable Energy*. National Geographic. https://www.nationalgeographic.org/encyclopedia/non-renewable-energy/.

NREL. RE Atlas [map]. Scale Not Given. "Renewable Energy Atlas." https://maps.nrel.gov/re-atlas/. (January 18, 2021).

NYSERDA. (n.d.). *New York Wind Energy Guide for Local Decision Makers: Wind Energy Basics* [PDF].

Size of States. State Symbols USA. (n.d.). https://statesymbolsusa.org/symbol-official-item/national-us/uncategorized/states-size.

Solar. U.S. Energy Atlas. (2020, October 28). https://atlas.eia.gov/datasets/solar-2.

Solar Energy Technologies Office. (n.d.). *Solar radiation Basics*. https://www.energy.gov/eere/solar/solar-radiation-basics

U.S. Energy Facts Explained. U.S. Energy Information Administration (EIA). (2020, May 7). https://www.eia.gov/energyexplained/us-energy-facts/.

Vann, Adam. (2012, February 1). *Energy Projects on Federal Lands: Leasing and Authorization*. Congressional Research Service.

Wind. U.S. Energy Atlas. (2020, October 28). https://atlas.eia.gov/datasets/wind-2.